Essence of Erbium doping in glasses as a laser material

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Abstract

Erbium-doped glasses have emerged as highly promising materials for solid-state lasers and optical amplifiers owing to the unique optical transitions of Er^{3+} ions, emission around 1.54 µm. This wavelength coincides with the low-loss transmission window of silica optical fibers and lies in the eye-safe region of the near-infrared spectrum, making erbium a central dopant for applications in optical communications, biomedical devices, remote sensing, and defense. Among various host matrices, sol–gel derived glasses have attracted significant attention because they provide a versatile, low-temperature route to synthesize bulk glasses, thin films, and waveguides with high compositional flexibility and chemical purity. The sol–gel process enables homogeneous dispersion of rare-earth ions and compatibility with integrated photonic device fabrication, features that are difficult to achieve using conventional high-temperature melting methods. Despite these advantages, erbium doping in sol–gel glasses faces several inherent challenges. A primary limitation is concentration quenching, which arises from clustering of Er^{3+} ions at doping levels beyond ~0.5–1 mol%. Such clustering promotes non-radiative energy transfer and reduces emission efficiency. Another major concern is the presence of hydroxyl (OH^-) groups, which are typically retained during the hydrolysis and condensation stages of the sol–gel process. OH^- groups exhibit strong absorption near 1.5 µm, leading to pronounced quenching of erbium luminescence. Additionally, thermal treatment is required to densify the sol–gel network and eliminate OH^-, yet excessive heating can also drive dopant segregation or crystallization, undermining optical performance. Therefore, optimization of both dopant chemistry and processing conditions is essential for achieving efficient laser action.

Keywords: erbium, laser, optical